Exploration of BSM Physics at the ILC

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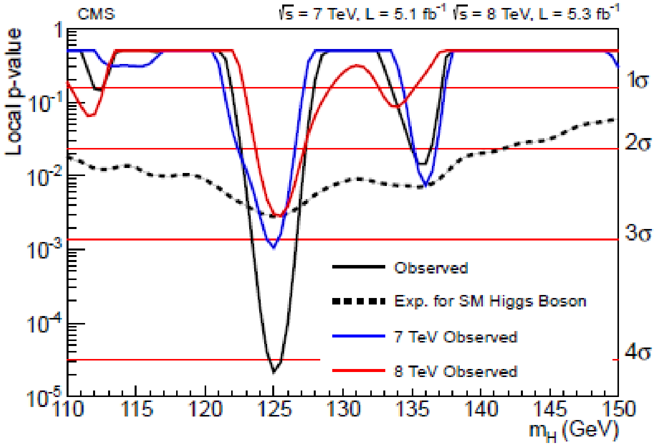
LHC searches for new particles

- A new particle annouced in July 2012



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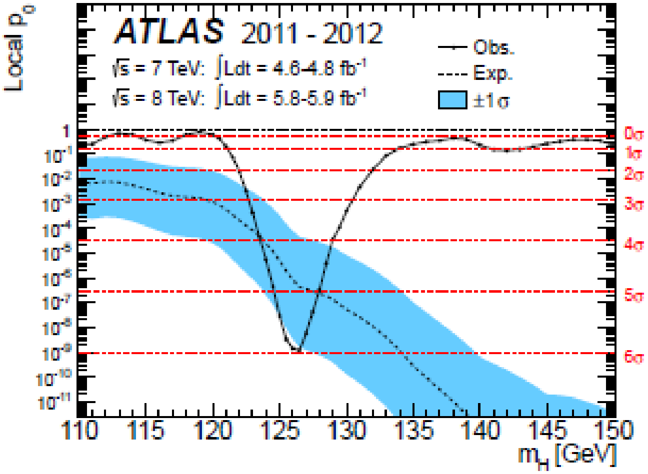

1207.7235

 S.Gori

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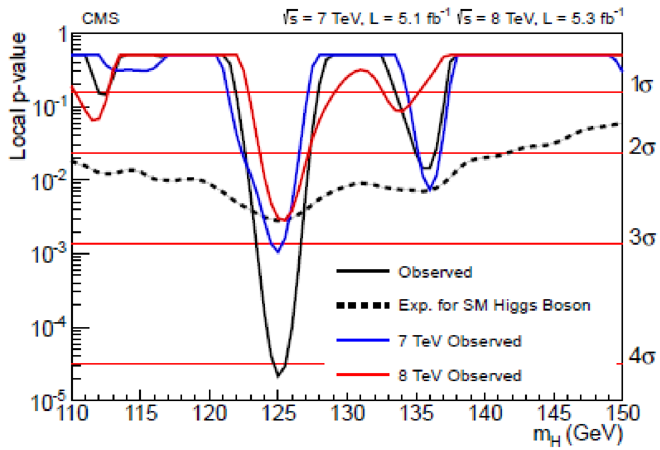

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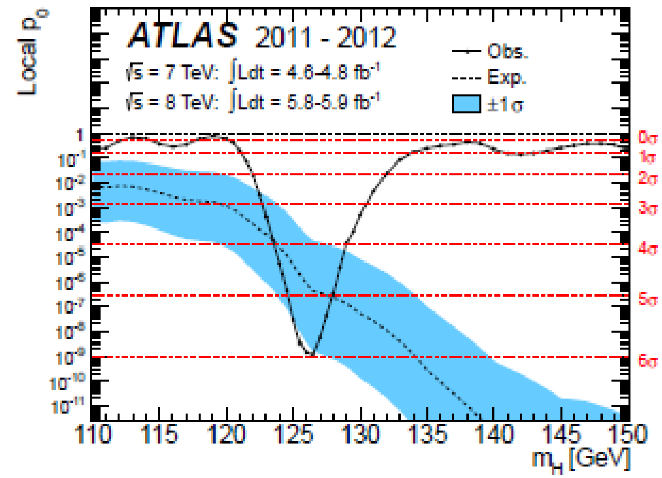

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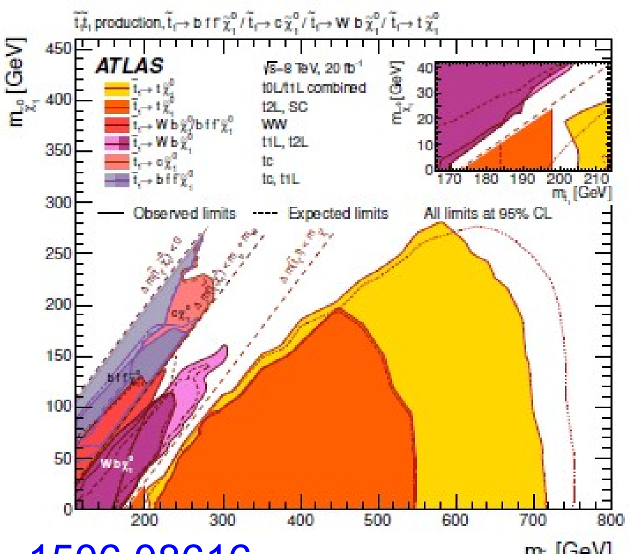
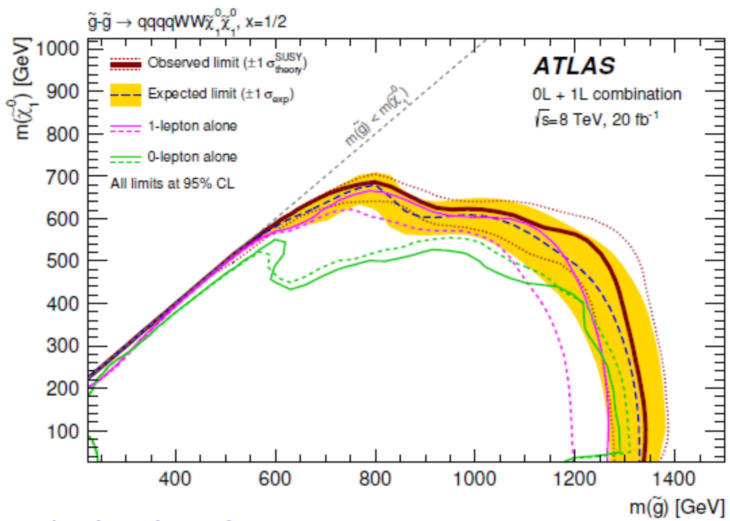
- No BSM particle discovered at Run I LHC



1506.08616



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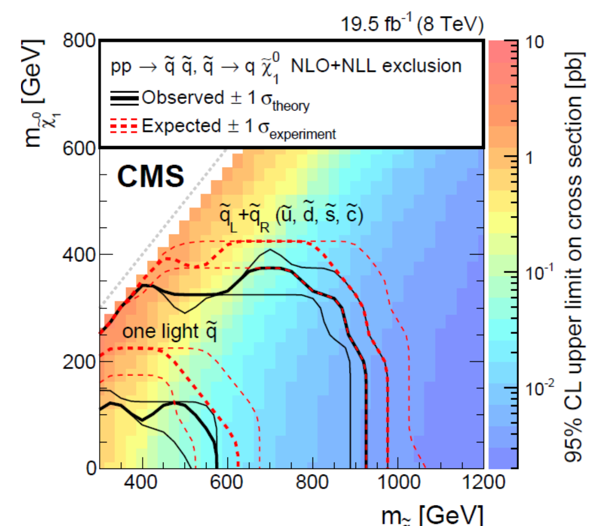
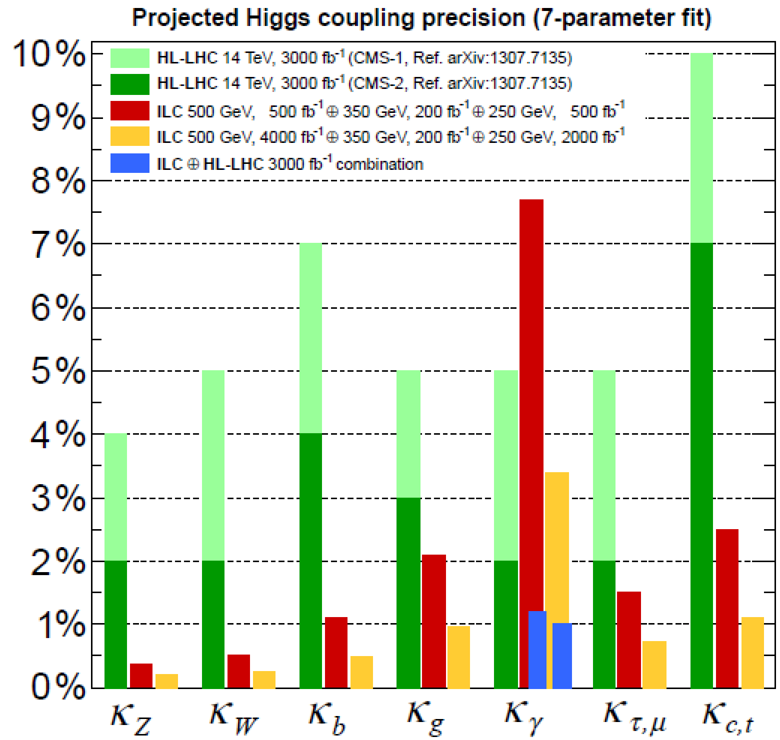


1502.04358

What a e^+e^- collider can tell us on NP

- A new particle annouced in July 2012

  Precision measurement of its couplings



1506.05992

- No BSM particle discovered at Run I LHC

  What can the ILC tell us about new resonances?

  Some very interesting questions I want to discuss in this talk:
  What about:

  1. Light Staus?
  2. Light Higgsinos?
  3. New (rare) decay modes of the Higgs?

1. Light staus

- Probably the most difficult SUSY particles to be looked for at the LHC
- Searches at Run I did not push the bounds beyond LEP

$pp \to \tilde{\tau}_1 \tilde{\tau}_1 \to (\tau \chi_1^0)(\tau \chi_1^0)$ ATLAS, 1407.0350

Best bound:

for $m_{\tilde{\tau}_L} = 93.1\,\text{GeV},\ \sigma(pp \to \tilde{\tau}_L \tilde{\tau}_L) = 0.22\,\text{pb}$

excluded: 0.28 pb

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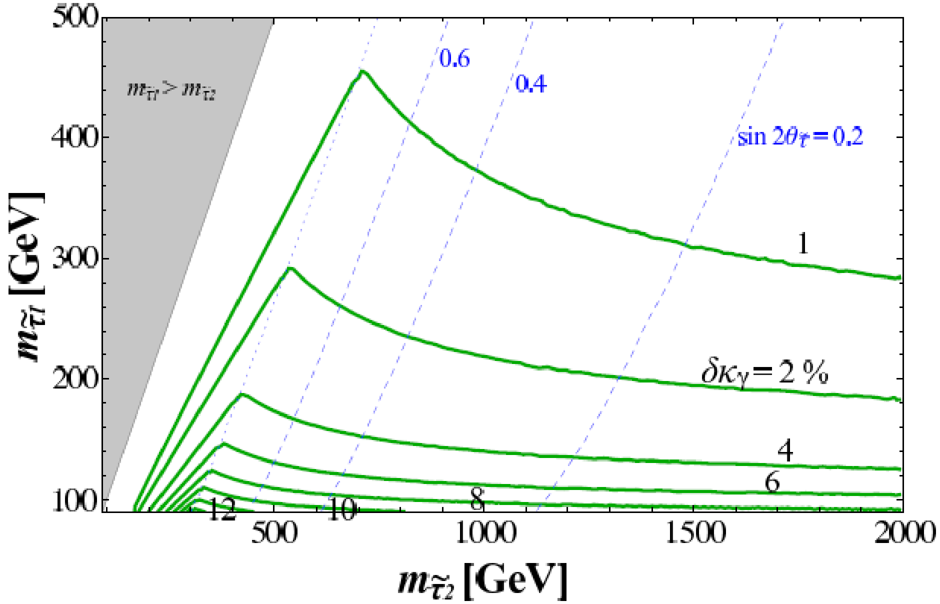
- Theoretically very interesting
  - DM scenarios with stau-neutralino coannihilation
  - Good candidate to enhance the Higgs di-photon rate

Carena, SG, Shah, Wagner, 1112.3336

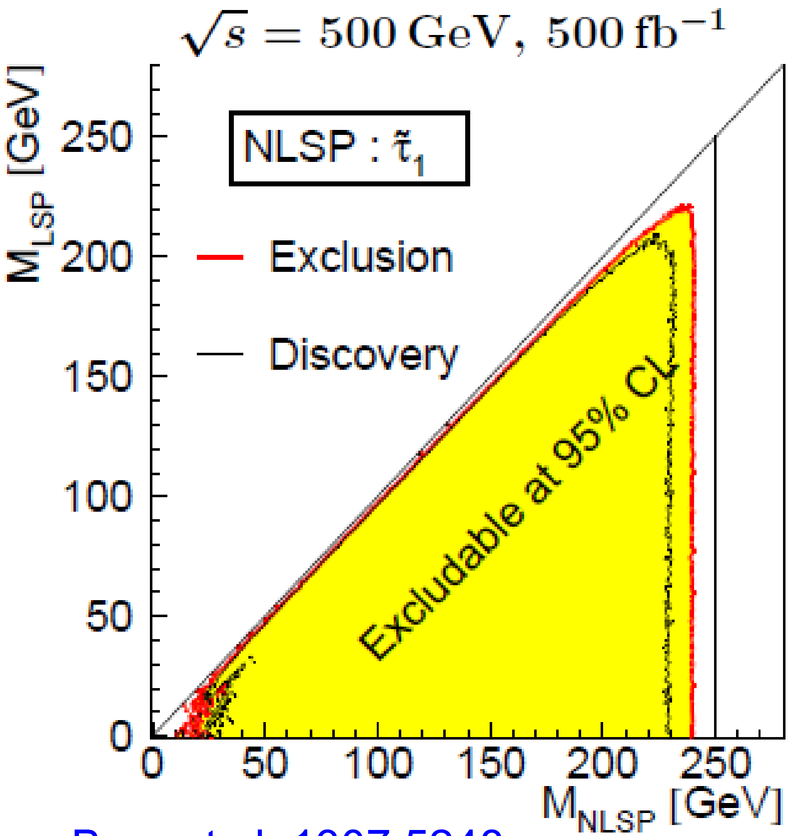


Endo, Kitahara, Yoshinaga, 1401.3748

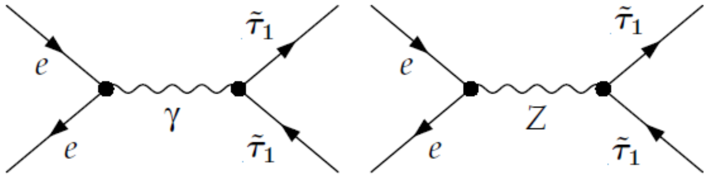
3 free parameters: $m_{\tilde{\tau}_1}$, $m_{\tilde{\tau}_2}$, $\theta_{\tilde{\tau}}$
one of which ($\theta_{\tilde{\tau}}$) constrained
by vacuum stability bounds

Carena, SG, Low, Shah, Wagner, 1211.6136

Light staus at the ILC



Baer et al. 1307.5248



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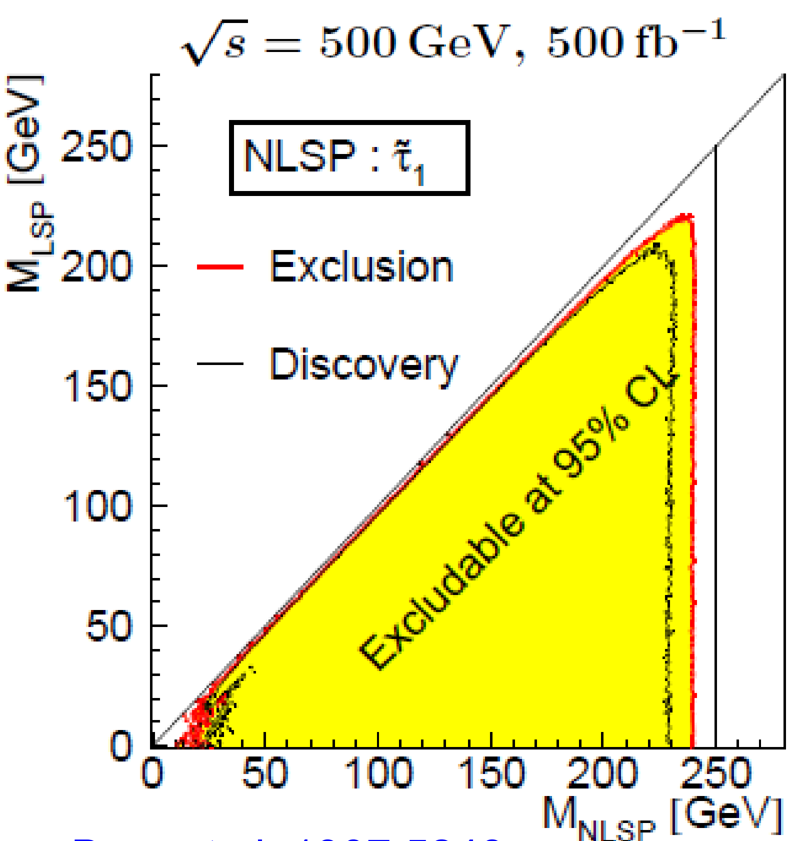

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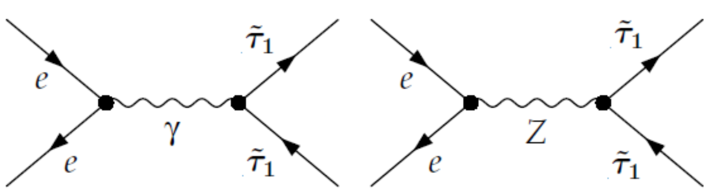


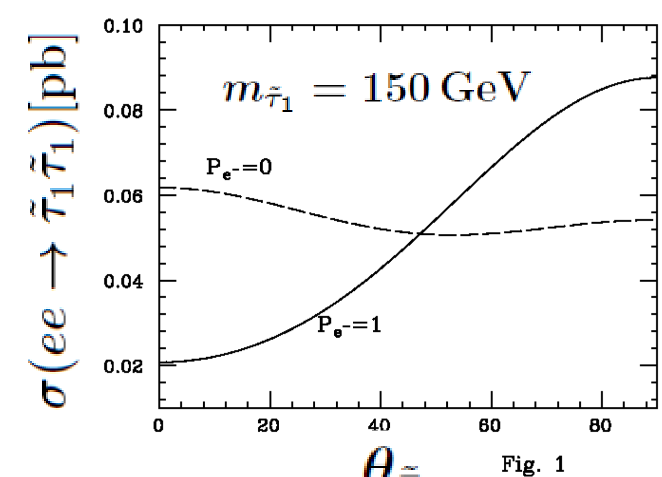
What about the $\tilde{\tau}_1 \tilde{\tau}_2$ production?

Precise determination of the stau spectrum:

- With threshold scan
  $\tilde{\tau}_1$ mass with O(1GeV) uncertanty
  See for example
  Belanger et al 0803.2584

- Mixing angle between the two staus determined from the measurement of the cross section

  $\theta_{\tilde{\tau}}$ with (2-3)% uncertainty



Nojiri, 9412374

- LSP composition determined by the polarization of the tau from the stau decay: $\tilde{\tau}_1 \to \tau \tilde{\chi}^0_1$

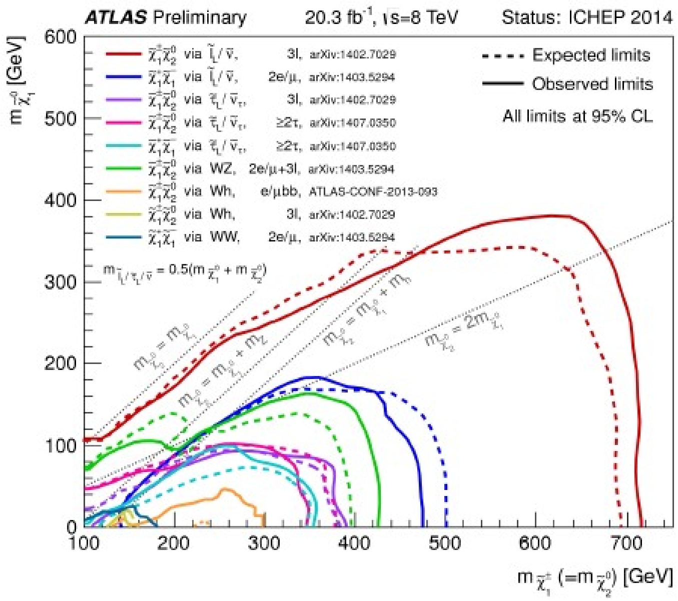
2. Compressed (EW) spectra (1)

- SUSY LSP can be a good DM candidate
(combination of Higgsino, Wino and Bino)

  - Well tempered neutralino: not too large mass splitting between LSP and NLSP Arkani-Hamed et al., 0601041
  - If DM is a pure state, then very small mass splitting
  Examples: Wino DM with $\Delta m \sim 166$ MeV
  Higgsino DM with $\Delta m \sim 355$ MeV

Why is it interesting?

- Small mass splitting is difficult to look for at the LHC
 Soft decay products and small MET



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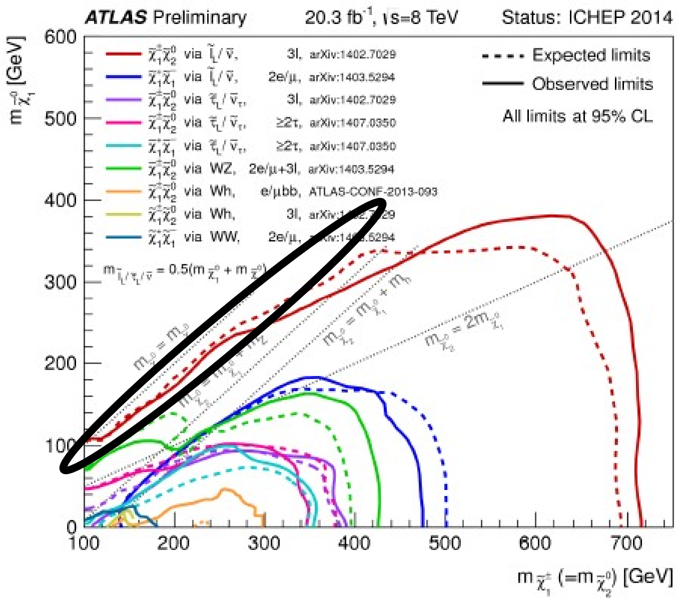


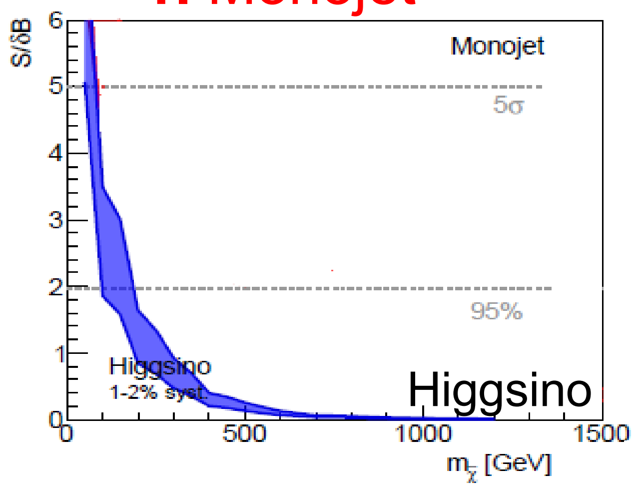
Why is it difficult?

2. Compressed (EW) spectra (2)

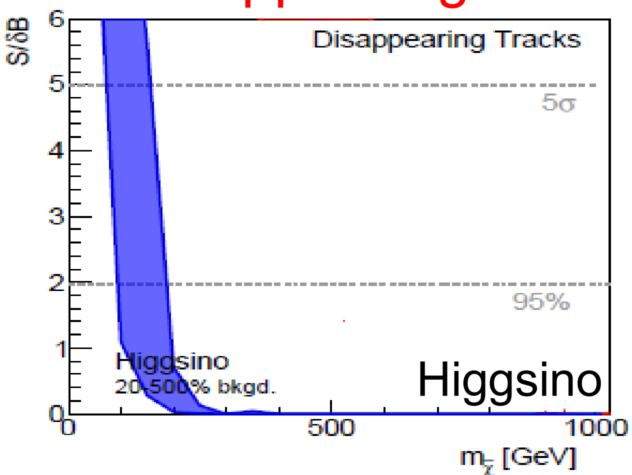
- A particularly interesting scenario: light Higgsinos
Higgsinos are the first particles to be light because of naturalness arguments

- Some theory proposal for improving the search for EW compressed spectra at the LHC

1. Monojet



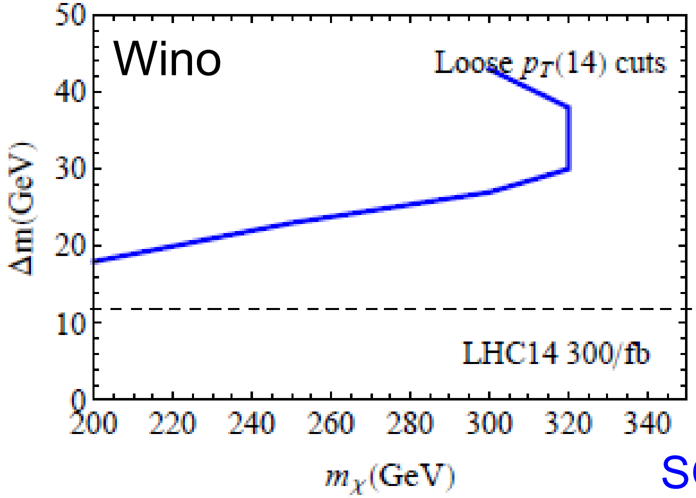
2. Disappearing tracks



Low, Wang, 1404.0682

See also Schwaller, Zurita, 1312.7350, Baer et al. 1401.1162, ...

3. ISR jet + soft leptons



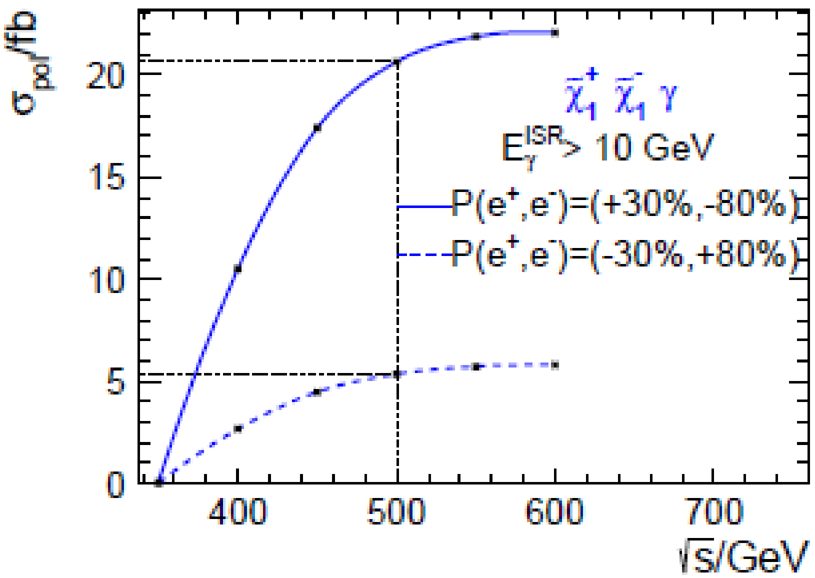
See also Han et al. 1401.1235
Baer et al.1409.7058

SG, Jung, Wang, 1307.5952

Light Higgsinos at the ILC

- Production of a pair of Higgsinos in association with a ISR photon at the ILC

$$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-\gamma \to (\pi\tilde{\chi}_1^0)(\ell\nu\tilde{\chi}_1^0)\gamma$$



For the benchmark dM770 in
Berggren et al. 1307.3566

$$m_{\tilde{\chi}_1^\pm} = 167.4\,\mathrm{GeV}$$

$$\Delta_{\tilde{\chi}_1^\pm - \tilde{\chi}_1^0} = 770\,\mathrm{MeV}$$

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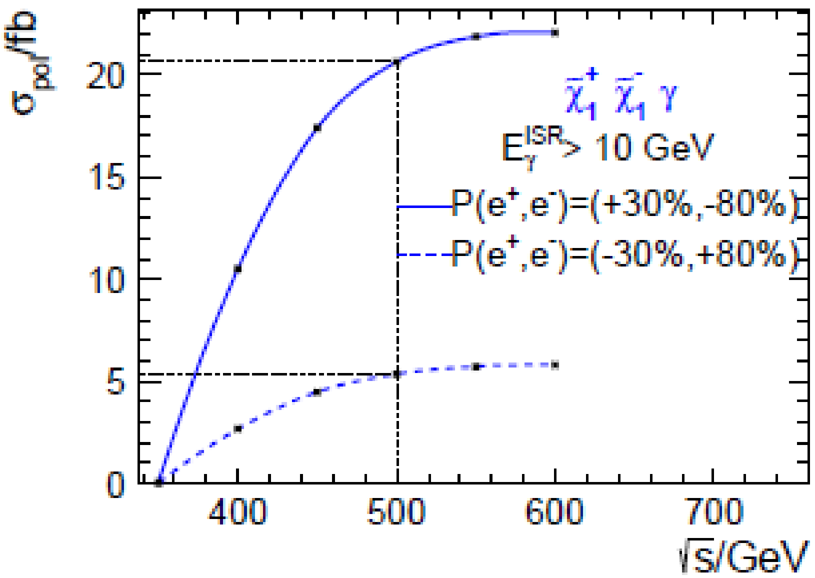

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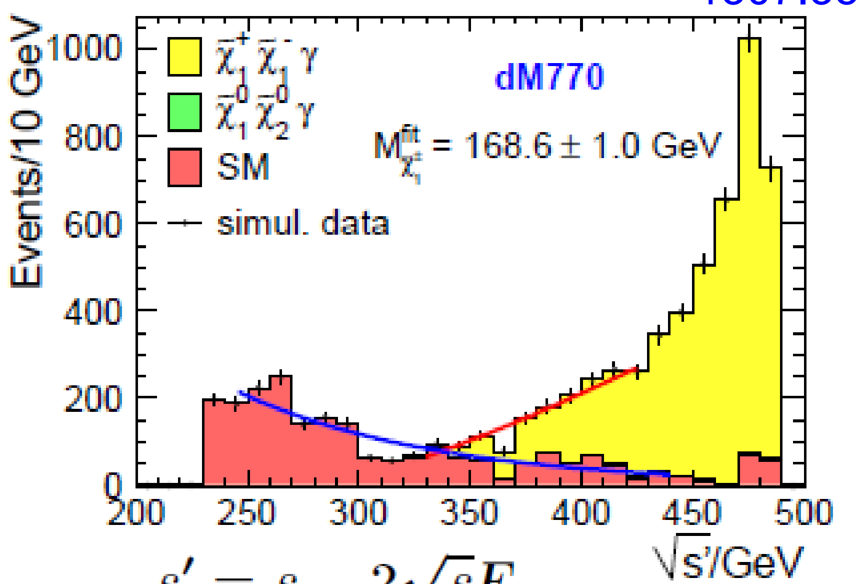
- Mass of the Higgsino determined from a fit to the distribution near the end point

Berggren et al. 1307.3566



$$s' = s - 2\sqrt{s}E_\gamma$$

- Mass splitting between NLSP and LSP determined by fitting the energy distribution of the pion coming from the Higgsino decay

$$\Delta^{rec}_{\tilde{\chi}_1^\pm - \tilde{\chi}_1^0} = (810 \pm 40)\,\text{MeV}$$

3. Higgs (rare) exotic decays

- The ILC will be a Higgs factory:

$$\sqrt{s} = 500\,\mathrm{GeV},\ \mathcal{L} = 500\,\mathrm{fb}^{-1}$$
$$\sqrt{s} = 350\,\mathrm{GeV},\ \mathcal{L} = 200\,\mathrm{fb}^{-1}$$
$$\sqrt{s} = 250\,\mathrm{GeV},\ \mathcal{L} = 500\,\mathrm{fb}^{-1}$$

After a luminosity upgrade: ⇒ More than a million Higgses

$$\sqrt{s} = 500\,\mathrm{GeV},\ \mathcal{L} = 3500\,\mathrm{fb}^{-1}$$
$$\sqrt{s} = 250\,\mathrm{GeV},\ \mathcal{L} = 1500\,\mathrm{fb}^{-1}$$

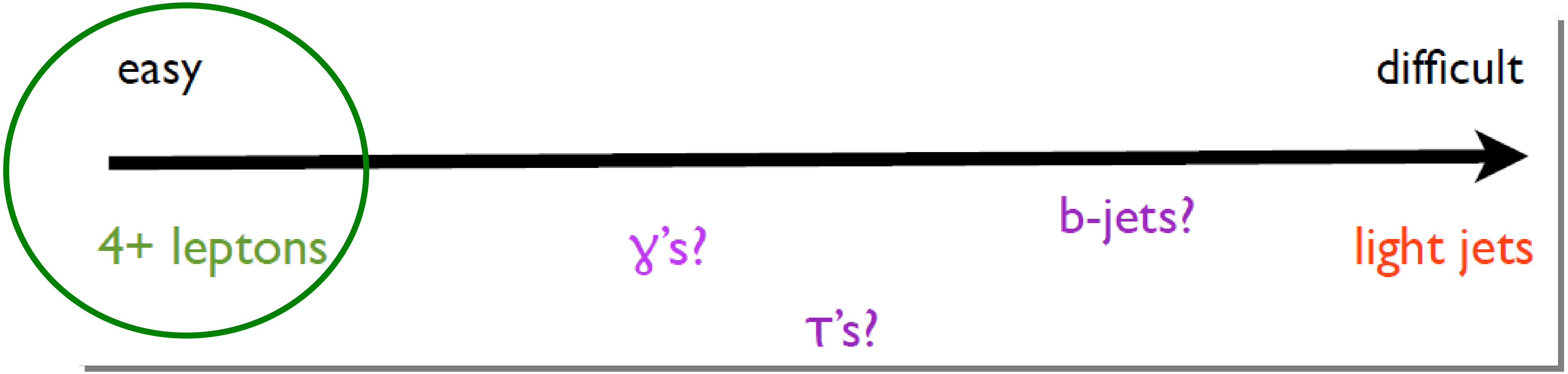
LCC Physics Working Group, 1506.05992

- The Higgs can have new decay modes: $h \longrightarrow$ NP particles
  - Models for DM, neutral naturalness, baryogenesis, ...
  - At the LHC, the determination of the Higgs total width has some model dependence and is at the level of ~10% at the HL-LHC (Higgs coupling fits, ZZ off-shell measurements, γγ interference effects, ...)
  - At the ILC, model independent determination of the Higgs total width from Zh production. Uncertainty at the level of ~2%

Higgs (rare) exotic decays at the ILC

Any chance to discover Higgs branching ratios to NP particles below 2%?

Looking "directly" for rare new decays of the Higgs:



Example:

$h \longrightarrow ZZ_D \longrightarrow 4l$

These can be seen by the LHC pretty easily:
BRs ~ 10^{-6} – 10^{-7} can be probed by the HL-LHC

Curtin, Essig, SG, Shelton 1412.0018

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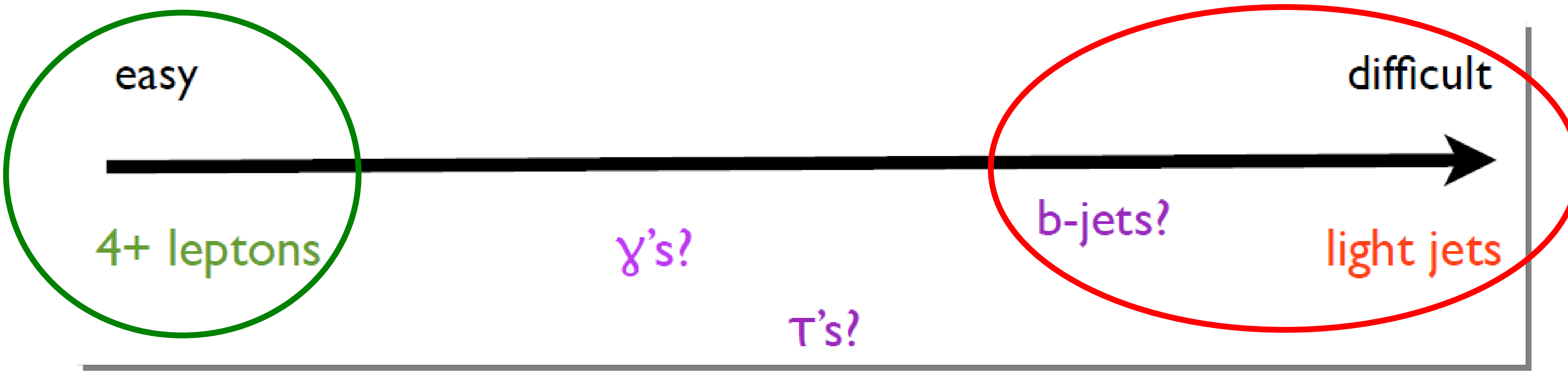

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Curtin, Essig, SG, Shelton 1412.0018

Example: (as in the NMSSM)
$h \longrightarrow ss \longrightarrow 4b$

Background limited at the LHC.
Theory studies show that BRs ~ 0.1 might be reached Cao et al, 1309.4939

What can the ILC say about these difficult decay modes?

Conclusions

In addition to precision Higgs and top measurements ...

The ILC offers impressive opportunities to probe New Physics scenarios difficult for the LHC

1. Light staus
2. Light Higgsinos

} Connection to Dark Matter models

3. New (rare) decay modes of the Higgs?

Closing the loopholes